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Dairy Farm Cost Efficiency

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ABSTRACT

A stochastic cost equation was estimated for US dairy farms using national data from the production year 2000 to determine how farmers might reduce their cost of production. Cost of producing a unit of milk was estimated into separate frontier (efficient) and inefficiency components, with both components estimated as a function of management and causation variables. Variables were entered as impacting the frontier component as well as the efficiency component of the stochastic curve because a priori both components could be impacted. A factor that has an impact on the cost frontier was the number of hours per day the milking facility is used. Using the milking facility for more hours per day decreased frontier costs; however, inefficiency increased with increased hours of milking facility use. Thus, farmers can decrease costs with increased utilization of the milking facility, but only if they are efficient in this strategy. Parlors compared with stanchions used for milking did not decrease frontier costs, but decreased costs because of increased efficiency, as did the use of a nutritionist. Use of rotational grazing decreased frontier costs but also increased inefficiency. Older farmers were less efficient.
Key words: cost, efficiency, stochastic cost function

INTRODUCTION

Profits vary across dairy farms, and various studies have investigated factors determining dairy farm success or profitability (Kauffman and Tauer, 1986; Williams et al., 1987; McGilliard et al., 1990). Recently, Gloy et al. (2002) found production management factors such as larger farm size, greater rate of milk production, and use of parlors rather than stanchion milking systems, had a positive impact on dairy farm profitability. They found that measures of human capital such as education and age did not affect profits. Type of accounting systems used and debt use did affect profits. It might be that better record keeping and monitoring could allow farms to determine the source of cost inefficiency. Jackson-Smith et al. (2004) found only a weak link between understanding of financial concepts and greater dairy financial returns. Mishra and Morehart (2001) found that participation in extension activities and the use of extension agents were positively associated with dairy farm financial performance.

Using a latent variable approach, Ford and Shonkwiler (1994) found that management of the dairy herd and herd size were more important determinants of farm financial success than financial or crop management. They concluded that increases in dairy managerial ability would have a greater relative payoff than increasing herd size, supporting the findings of Tauer and Mishra (2006) that efficiency was more important than farm size in reducing net production costs. Alvarez and Arias (2003) found in Spanish dairy farms that observed diseconomies of size might be offset by sufficient increases in managerial ability, in which managerial ability is measured by technical efficiency.

Adoption of various production practices or technologies also may impact profitability (Foltz and Chang, 2002). El-Osta and Johnson (1998) investigated use of advanced milking parlors but concluded that this technology did not have a significant effect on net farm income in traditional dairy states. Instead, these studies found that production per cow was a strong factor associated with dairy farm profitability. A number of reasons explain why production per cow is limited, including inferior genetics, low quality feeds, and disease incidence.

The number of dairy farms in the United States decreased significantly during the last decade, from 180,640 operations in 1991 to 105,250 operations in 2000 (Blayney, 2002). Most of this decline came from small dairy farms. Much research shows that cost decreases with farm size (Stefanou and Madden, 1987). Recent cost studies of dairy production found smaller unit costs associated with larger production units, explaining why smaller farms may have exited the dairy industry (Bailey et al., 1997). Tauer and Mishra (2006) found the efficient small US dairy farm produced milk at a cost only slighter greater than the efficient large farm, but the typical inefficient small dairy farm had

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much greater cost than the efficient, or even the inefficient large dairy farm.

The purpose of this paper is to explore determinants of cost and inefficiency to identify the managerial changes that dairy farms can make to reduce the cost of production. That is accomplished by estimating a stochastic unit cost curve in which both the frontier and efficiency components of that cost curve are functions of causation variables. Frontier costs are minimum costs producing milk using some given technology or technique when the farmer is completely efficient. Inefficiency causes the costs of using the technology or technique to be greater than these minimum costs. Some farmers using the technique are able to produce at minimum cost, whereas other farmers using the technique have greater costs and are thus measured as cost inefficient. Separation of costs into frontier and inefficiency components would be valuable in devising education programs to ensure the US dairy farm remains competitive in the world market. Frontier costs are feasible for the very best farmers and should be achieved by all farmers.

MATERIALS AND METHODS

Frontier Curve and Efficiency

A technology or management practice may reduce unit cost of production but only if a farmer is efficient implementing the technology or practice. Some farmers may find that the technology or practice does not reduce cost of production as expected because they are inefficient in implementation. In an empirical estimation of the impact of technology and practice on cost of production, it is important to separate out the 2 types of cost components. Frontier costs are the costs with the very best management; inefficiency costs are greater observed costs because of poor management. This approach is in contrast to estimating a cost curve fitting average costs, explaining what the average farmer is capable of accomplishing.

We decompose observed total unit cost into frontier and efficiency components and estimate determinants that may impact the frontier cost and cost efficiency. Most producers would like to minimize total per unit cost of production in a competitive market. That can be accomplished by reducing frontier cost production, becoming more cost efficient, or both. An average or unit total cost curve for a farm is estimated as a function of a covariate set X_i, an error term v_i, and an efficiency term u,

$$c_i = f(X_i, \beta) + v_i + u(Z_i,\delta),\ u(Z_i,\delta) \geq 0 \qquad [1]$$

where c_i is the cost of production per hundredweight (**cwt**) of milk on farm i, X_i are the covariates that affect costs, and the v_i error term is independent of X_i, Z_i, and u. The efficiency term, u, is specified as a function of a set of covariates Z_i, containing set elements that may overlap with the covariate set X_i. The β vector is the coefficient for the frontier cost curve, whereas the δ vector is the coefficient for the efficiency cost curve.

The measurement error term, v, is modeled as an independent, identically distributed normal distribution $N(0,\sigma^2)$, and the efficiency term, u, is modeled as a truncated positive half-normal distribution, $N^+(g(Z_i), \sigma^2)$. This allows the measurement error term for an individual farm observation to be either negative or positive, but the efficiency term u, which will be greater than 0, will shift with covariates Z_i. An alternative specification for the efficiency term is $N^+ (0, h(Z_i)^2)$, where the variance of the truncated half-normal changes with the covariates. In addition, both mean and variance of the truncated half-normal can shift with covariates. We elect to shift the mean only because shifting the variance as well as the frontier cost with the same covariates did not provide estimated results because of nonconvergence. Even then, because $g(Z_i)$ is the mean of the underlying distribution before truncation, both the mean and variance of the efficiency u are functions of $g(Z_i)$ and σ^2. Estimation is by maximum likelihood simultaneously estimating the f and g functions with the specified error and efficiency structures.

The procedure used is typically referred to as a stochastic cost function. Others (Aigner et al., 1977; Battese and Corra, 1977; Meeusen and van den Broeck, 1977) introduced stochastic frontier production functions. They decomposed the typical error term of a regression model into an efficiency component plus a measurement error and used maximum likelihood estimation to estimate simultaneously the parameters of the production function as well as inefficiency and measurement error. The approach is now routinely used to estimate not only production but also profit and cost functions. More recently, beginning with Kumbhakar et al. (1991) and Battese and Coelli (1995), the inefficiency component also has been simultaneously estimated as a function of causation factors. Wang and Schmidt (2002) provided a discussion and assessment of the technique. Lawson et al. (2004) recently applied a stochastic production function to the dairy industry and emphasized the impact of disease control on production efficiency but also looked at the impact of other management factors, such as housing type.

Because variables in set X and set Z may overlap, a change in those variables impacts cost in 2 ways. One impact will be a shift in the frontier curve; the other impact will be a change in efficiency. The impact from the frontier cost curve is simply the first derivative of the frontier cost curve with respect to the variable x_k as follows:

$$\partial f(X_i,\beta)/\partial x_k \qquad [2]$$

where the marginal impact is the same for each farm with identical covariate values.

Impact of a variable k on efficiency will be farm specific; however, Wang (2002) showed how the marginal effect on farm efficiency is calculated when either or both the mean and variance of the truncated normal are functions of the covariates. We estimated only the mean as a function of the covariates. Specifying g as a linear function, $g = Z \times \delta$ such that $\mu_i = Z_i \times \delta$, and defining $\Lambda = \mu_i/\sigma_i$, and $\lambda = \phi(\Lambda)/\Phi(\Lambda)$, where ϕ is the normal probability function and Φ is the normal cumulative function allows computation of the expected marginal efficiency impact of a variable x_k on farm i as follows:

$$\partial E(\mu_i)/\partial x_k = \delta_k \times (1 - \Lambda \times \lambda - \lambda^2) \qquad [3]$$

where the term $(1 - \Lambda \times \lambda - \lambda^2)$ varies by farm, but δ_k is constant across farms.

Frontier and efficiency components of Equation [1] were estimated jointly using maximum likelihood estimation. The data were collected using a stratified random sample with an enhanced sample of larger farms because few large farms would have been surveyed with a random sample. Estimation was by weighted maximum likelihood with weights applied outside the likelihood value of each observation to account for the stratified random sample with unequal probability weights.

Survey Data

Data were extracted from the Dairy Production Practices and Costs and Returns Report (Agricultural Resource Management Survey Phase II, commonly referred to as ARMS). Observations were collected using a survey jointly administered by the National Agricultural Statistics Service and Economic Research Service of the USDA for dairy production during calendar year 2000. The survey collects data to measure the financial condition and operating characteristics of farm businesses, the cost of producing agricultural commodities, and information on technology use and management practices. Unfortunately, prices of inputs were not collected, and thus it was not possible to estimate a standard cost function in which cost is a function of input prices. Rather, cost per cwt of milk produced was estimated as a function of farm characteristics and practices, which we will refer to as a cost equation.

The target population for the survey was farms milking 10 or more cows in the 22 major dairy states. The sample is a multiframe, probability-based survey in which farms were selected randomly from groups of dairy farms stratified by farm characteristics such as farm size, with greater coverage in the primary dairy production states. The survey design allowed each sampled farm to represent a number of farms that are similar. That number is referred to as the expansion factor, which is defined as the inverse of the probability of the surveyed farm being selected. The expansion factor is also referred to as the observation's weight. Each version of the survey has a unique expansion factor that expands the sample to the target population. On-farm enumerators collected the data using a 36-page survey instrument.

Dairy costs and returns for each farm have been calculated by USDA and are used to compute the cost of production per cwt of milk sold (Short, 2004). Costs include all costs, including family labor and capital costs. To calculate the total cost of producing milk per cwt of milk, sales of livestock and other nonmilk income were subtracted from total farm costs, which were then divided by the cwt of milk sold. This approach presumes the primary operation on these farms is milk production and the cost of producing other income is equal to that income. Fixed costs include family labor and capital costs. The dependent variable was the total unit cost of producing milk where units are the cwt of milk sold from each farm. Milk is priced and sold in the United States by cwt.

Total costs per cwt of milk ranged from 2 negative values to 17 observations with costs over \$100 per cwt of milk. Scrutiny of these farms revealed a variety of possible reasons for these extreme cost values. Some had large cattle sales, probably reflecting a profitable cattle-breeding program or partial herd liquidation. Others had extremely small production levels. Because many other reasons may have been responsible for extreme values, it was decided to use only farms with total cost greater than \$4.00 and less than \$35.00 per cwt of milk sold. Other farms were deleted because of missing age. This resulted in 749 observations. New weights were computed for the maximum likelihood estimation and estimated average efficiencies.

Variables that might influence cost of production and cost efficiency of an individual dairy farm are uncommon in farm data sets, but a number of these were collected in the survey instrument. These are reported and defined in Table 1. Each variable was entered as impacting the frontier component as well as the efficiency component of the stochastic curve because a priori both components could be impacted. An example is the years of formal education of the farmer. Greater

Table 1. Variables used to estimate frontier and efficiency unit costs for US dairy farms during 2000[1]

Variable name	Definition	Weighted mean value
COWS	Average number of milking cows during the year	125
FARMORGD	Type of ownership: 1 = partnership, family corporation, nonfamily corporation, or other; or 0 = individual	0.22
OP_AGE	Age of first or principal operator	48
PARLORD	Use of parlor to milk cows: 1 = parlor or 0 = no parlor (stanchion milking)	0.39
EDUC	Years of formal education: 1 = beyond high school or 0 = high school or less	0.30
COM_MILK	Computerized milking system: 1 = yes or 0 = no	0.07
COM_FEED	Computerized feeding system: 1 = yes or 0 = no	0.09
FEED_NUT	Use of a nutritionist: 1 = yes or 0 = no	0.72
FOR_TEST	Uses forage testing: 1 = yes or 0 = no	0.60
INTENSE	Hours per day milking system used	5.5
GRAZE	Use of rotational grazing: 1 = yes or 0 = no	0.22

[1]Data are from the Dairy Production Practices and Costs and Returns Report (Agricultural Resource Management Survey Phase II, commonly referred to as ARMS).

formal education may allow farmers to select the smallest cost technology to define the frontier cost function, and education also may allow farmers to be efficient in their use of leading-edge technology. The continuous variables COWS, AGE, and INTENSE were entered in natural logarithmic form to produce a nonlinear response to these variables. All remaining variables have 0 or 1 values. Because the included explanatory variables are not exhaustive, farm size as determined by the number of cows was included in the regressions to pick up residual frontier and efficiency costs correlated with farm size, serving as a proxy for these latent management variables.

Often variables that have been regressed on farm profitability or efficiency and found to be statistically significant are not true causation or management variables, but rather indicators of poor or good management. One such variable is production per cow. Production per cow may be small because of inferior genetics, low quality feeds, lack of disease control, or other poor management factors. A number of techniques collected in the data survey instrument, such as whether the milking units had automatic takeoffs, were highly collinear with included regression variables and thus were not included in the analysis. McBride et al. (2004), using the same data, did not find recombinant bovine somatotropin profitable, so that variable was not included. Finally, estimation with included state dummy variables was not successful even after trying various optimization algorithms and convergence tolerances.

RESULTS AND DISCUSSION

Table 2 reports estimated total unit cost stochastic cost curve, decomposed into frontier and inefficiency components. The frontier component shows the cost curve for an efficient farm. Results, however, also include inefficient farms, so the inefficiency component measures the inefficiency of those farms by variable. Estimated frontier unit cost curve has an intercept of 19.01 and a coefficient of 1.22 on ln(COWS). This implies that frontier unit cost increases slightly with size of the farm. This is in contrast to the results of Tauer and Mishra (2006) who found no relationship between frontier unit cost and size when farm size was the sole explanatory variable. Hoch (1976) and Dawson (1985) have found diseconomies of size in dairy farming, so when management factors are added to the cost equation that decrease costs, many of which are associated with farm size, the residual frontier cost curve apparently displays diseconomies of size. Increased size per se does not decrease costs—it is the factors associated with size that decrease costs. Two factors found to be statistically significant are efficiency and utilization of the milking facility.

Because the unit cost frontier displays diseconomies of size, going from the sample average of 125 to 225 cows, for instance, would increase the frontier unit cost curve by \$0.85/cwt. Movement from 225 to 1,000 cows further increases frontier unit cost by an additional \$1.69/cwt. These larger farms, however, are more cost efficient as discussed later, leading to a net unit cost reduction. Larger farms are most cost efficient as observed by Tauer and Mishra (2006).

Utilizing the milking system more intensively each day reduces the frontier total unit cost. Wagner et al. (2001) also discovered reduced costs in parlors used more hours per day. The average time that milking systems were used each day on the surveyed farms was 5.5 h. If those systems were used up to 10.5 h per day, the frontier total unit cost would fall by \$2.67/cwt. As will be discussed later, however, efficiency decreases with greater intensity of use, offsetting much, if not all,

Table 2. Estimated frontier and efficiency unit cost components for US dairy farms during 2000

Variable name	Definition of variable	Estimate[1]	SE of estimate	$P <$ (H_0:β_k=0)
Frontier				
CONSTANT	Intercept	19.01	6.48	0.00
Log(COWS)	Logarithmic value of average number of milking cows during the year	1.22	0.62	0.05
FARMORGD	Type of ownership: 1 = partnership, family corporation, nonfamily corporation, or other; or 0 = individual	0.85	0.80	0.29
Log(AGE)	Logarithmic value of age of first or principal operator	–2.44	1.69	0.15
PARLORD	Use of parlor to milk cows: 1 = parlor or 0 = no parlor (stanchion milking)	1.32	0.95	0.16
EDUC	Years of formal education: 1 = beyond high school or 0 = high school or less	–0.19	0.68	0.78
COM_MILK	Computerized milking system: 1 = yes or 0 = no	–0.82	1.45	0.57
COM_FEED	Computerized feeding system: 1 = yes or 0 = no	0.28	1.46	0.84
FEED_NUT	Use of a nutritionist: 1 = yes or 0 = no	0.56	1.20	0.64
FOR_TEST	Uses forage testing: 1 = yes or 0 = no	0.41	0.87	0.63
Log(INTENSE)	Logarithmic value of hours per day milking system used	–4.13	1.14	0.00
GRAZE	Use of rotational grazing: 1 = yes or 0 = no	–2.43	1.18	0.04
Efficiency				
CONSTANT	Intercept	13.45	11.25	0.23
Log(COWS)	Logarithmic value of average number of milking cows during the year	–8.52	1.94	0.00
FARMORGD	Type of ownership: 1 = partnership, family corporation, nonfamily corporation, or other; or 0 = individual	–1.16	1.40	0.41
Log(AGE)	Logarithmic value of age of first or principal operator	12.05	3.55	0.00
PARLORD	Use of parlor to milk cows: 1 = parlor or 0 = no parlor (stanchion milking)	–3.42	1.68	0.04
EDUC	Years of formal education: 1 = beyond high school or 0 = high school or less	0.59	1.24	0.63
COM_MILK	Computerized milking system: 1 = yes or 0 = no	1.18	2.45	0.63
COM_FEED	Computerized feeding system: 1 = yes or 0 = no	1.17	2.51	0.64
DAIRY_NUT	Use of a nutritionist: 1 = yes or 0 = no	–3.79	1.46	0.01
FOR_TEST	Uses forage testing: 1 = yes or 0 = no	0.61	1.32	0.64
Log(INTENSE)	Logarithmic value of hours per day milking system used	9.55	2.52	0.00
GRAZE	Use of rotational grazing: 1 = yes or 0 = no	2.96	1.73	0.09
$(1 - \Lambda \times \lambda - \lambda^2)$	—	0.67	0.23	0.01
σ_v	—	1.98	—	—
σ_u	—	6.69	—	—
Observations, n	—	749	—	—

[1]Coefficients based upon cost per hundredweight of milk produced.

of the frontier total unit cost saving depending upon usage increase.

Grazing, which is more common on small dairy farms, decreases the frontier unit cost by \$2.43/cwt. White et al. (2002) found pasture systems were as profitable as confinement systems. No other variables were statistically significant in the frontier component of the cost function.

Variables statistically significant in the inefficiency component of the estimated unit cost equation reported in the bottom half of Table 2 were number of cows, age of the operator, use of a parlor for milking, use of a herd nutritionist, intensity of using the milking system, and grazing. Larger farms are more efficient and older operators are less efficient. Lawson et al. (2004) similarly found younger dairy farmers to be more efficient. Use of a parlor rather than stanchions for milking increased efficiency, but using the milking system more intensively decreased efficiency. So although use of a parlor for milking does not impact frontier costs, parlors permit many farms to become more cost efficient and thus reduce their observed production costs. Lawson et al. (2004) found free-stall housing (loose housing system) to be more efficient, but did not include milking system in their analysis. Use of a herd nutritionist increases efficiency, supporting the finding by Vandehaar (1998) that efficiency of nutrient use is a major factor affecting farm profitability on modern dairy farms. Yet what specific service nutritionists provide to these farms was not questioned in the survey form and may have ranged immensely in level of service. This variable also may be a proxy for use of production advice in all facets of the business.

A number of variables did not impact the frontier unit cost or unit cost efficiency. Most significantly, use of a computer in the milking system or the feeding system did not have an impact. Only 7% or about 53 of the survey farms used a computerized milking system, and only 9% used a computerized feeding system. More than half, or 59% of the farms forage-tested, but that did not have an estimated impact on either the frontier unit cost or unit cost efficiency. Finally, neither number of years of formal education nor number of managers on the farm had an impact on the frontier total unit cost or total unit cost efficiency.

Table 3. Impact of statistically significant variables on frontier unit cost and efficiency unit cost for US dairy farms during 2000

Variable	Definition of variable	Frontier[1] ($)	Efficiency[1] ($)	Combined ($)
Ln(COWS) 125 to 225 cows[2]	Logarithmic value of average number of milking cows during the year	0.85	–3.96	–3.11
Ln(AGE) 48 to 58 yr[2]	Logarithmic value of age of first or principal operator	NA[3]	1.53	1.53
PARLORD	Use of parlor to milk cows: 1 = parlor or 0 = no parlor (stanchion milking)	NA[3]	–2.29	–2.29
DAIRY_NUT	Use of a nutritionist: 1 = yes or 0 = no	NA[3]	–2.54	–2.54
Ln(INTENSE) 5.5 to 10.5 h[2]	Logarithmic value of hours per day milking system used	–2.67	4.14	1.47
GRAZE	Use of rotational grazing: 1 = yes or 0 = no	–2.43	1.98	–0.45

[1]Estimates are from equation in Table 2 with coefficients ($P < 0.10$).

[2]Because logarithmic derivatives are not constant (linear), beginning and ending values are used to determine impact of change.

[3]NA = Not applicable because the variable was not statistically significant.

Impact that statistically significant variables have on efficiency cost measured in cwt of milk is farm specific as given by Equation [3]. Impacts of these factors can be averaged over all farms using the stratified sample weights. The average weighted value of the term ($1 - \Lambda \times \lambda - \lambda^2$) was 0.67, so each estimated coefficient δ_k in the efficiency coefficients section of Table 2 was multiplied by 0.67 to arrive at per unit costs of efficiency for each variable. Table 3 shows these impacts along with the impacts from the corresponding frontier component if those corresponding variables were statistically significant.

Nonlogarithmic variables have a constant impact (first derivative) on both frontier and efficiency costs. Thus, use of a parlor does not decrease the frontier unit cost (statistically), but would increase efficiency by $2.29/cwt of milk produced. Likewise, use of a nutritionist does not decrease the frontier unit cost, but would increase efficiency by $2.54/cwt of milk. These results imply that neither use of a parlor for milking nor utilizing the services of a nutritionist reduce costs of the efficient farm, but they do reduce the cost of the average farm. In contrast, grazing reduces frontier unit cost by $2.43/cwt, but decreases efficiency unit cost by $1.98/cwt, leading to a net unit cost decrease of $0.45/cwt. Successful grazing can reduce costs for the efficient farm, but many farms apparently find grazing challenging because grazing increases efficiency costs.

Impacts of the remaining logarithmic variables depend upon beginning and ending values of these variables. Increasing cows from the sample weighted average of 125 to 225 would have a net impact of –$3.11/cwt on combined unit cost, consisting of an increase of $0.85/cwt in frontier unit cost, but an increase of $3.96/cwt in efficiency unit cost. Thus, larger farms on average have less net unit costs. A dairy producer who is 48 yr old (sample average) compared with one who is 58 yr old would be less efficient by $1.53/cwt. Tauer and Lordkipanidze (2000) found older US farmers less efficient than younger farmers. A farmer cannot turn back the clock but needs to be cognizant of decreases in efficiency that might occur with age, and plan business transition accordingly.

Increasing use of the milking system from the sample average of 5.5 h to 10.5 h/d would increase combined unit cost by $1.47/cwt. The frontier unit cost would decrease by a significant $2.67/cwt, but efficiency unit cost decreases by $4.14/cwt. Thus, increased utilization of the milking facilities would decrease frontier unit cost as expected, but efficiency decreases (or inefficiency increases) on the average farm studied. Efficiently operated farms demonstrated that costs can be decreased by using the milking facility more hours per day. These farms apparently spread costs of the milking system over more hours of use while keeping production and other costs under control.

CONCLUSIONS

A stochastic-cost equation was estimated for the US dairy industry in which both the cost frontier and cost inefficiency is a function of causation variables. The USDA data from the production year 2000 were used. The most significant factors that decrease production costs, other than farm size, are use of a nutritionist followed by use of a parlor for milking.

The factor with the greatest impact on the cost frontier is the number of hours per day the milking facility is used. Using the milking facilities more hours per day decreased frontier costs. Inefficiency increased with increased hours of use such that there was a net increase in unit costs on the average farm studied. Thus, farms can decrease costs with increased utilization of the milking facilities, but only if they are efficient in this strategy. Farmer age increased unit cost of production because older farmers were less efficient. Parlors did not decrease frontier unit costs but did decrease unit costs because of increased efficiency, as did the use of a nutritionist. Use of rotational grazing decreased frontier costs but decreased efficiency, with a net reduction in cost of production per cwt of milk sold.

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